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Abstract: The spaceborne ESA-mission CHRIS/PROBA (Compact High Resolution Imaging Spectrometer-Project for On-board Autonomy) provides hyperspectral and multidirectional data of selected targets spread over the world. While the spectral information content of CHRIS/PROBA data is able to assess the biochemistry of a vegetation canopy, the directional information can describe the structure of an observed canopy. However, a thematic analysis of the hyperspectraldirectional data requires dedicated geometric and radiometric pre-processing of the CHRIS/PROBA acquisitions. Only careful pre-processing will provide a spatially, spectrally, directionally and temporally consistent data set – a prerequisite for subsequent quantitative and qualitative retrieval of biochemical and –physical vegetation parameters. In this study we propose and validate such a comprehensive preprocessing on a data set over rugged, mountainous terrain in the Swiss Alps. The proposed geometric correction relies on a parametric approach taking into account the viewing geometry and geometric distortion due to the sensor, platform and topography. Potentially, this method provides high accuracy, robustness and consistent results over the full image. The performance of the geometric correction is validated relative to geolocated digital map and vector data available for parts of the CHRIS scenes. Atmospheric correction of the hyperspectral-directional data involves the physically based radiative transfer model ATCOR. The ATCOR model corrects for the effects of the atmosphere as well as for illumination effects caused by rugged terrain influencing the satellite image. Parallel to the spaceborne data also spectrodirectional ground data have been acquired with the FIGOS Goniometer over an alpine meadow. Spectral measurements of various field targets complement the data set. The field data allow for a validation of the obtained top-of-canopy Hemispherical-Directional-Reflectance-Factor (HDRF) in its full directional resolution.

Originally published at:
Kneubühler, Mathias; Koetz, Benjamin; Richter, Rudolf; Schaepman, Michael E; Itten, Klaus I (2005). Geometric and radiometric pre-processing of CHRIS/PROBA data over mountainous terrain. In: 3rd CHRIS/Proba workshop, Frascati, Italy, 21 March 2005 - 23 March 2005, European Space Agency.

GEOMETRIC AND RADIOMETRIC PRE-PROCESSING OF CHRIS/PROBA DATA OVER MOUNTAINOUS TERRAIN

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ABSTRACT/RESUME

The spaceborne ESA-mission CHRIS/PROBA (Compact High Resolution Imaging Spectrometer-Project for On-board Autonomy) provides hyperspectral and multidirectional data of selected targets spread over the world. While the spectral information content of CHRIS/PROBA data is able to assess the biochemistry of a vegetation canopy, the directional information can describe the structure of an observed canopy.

However, a thematic analysis of the hyperspectral-directional data requires dedicated geometric and radiometric pre-processing of the CHRIS/PROBA acquisitions. Only careful pre-processing will provide a spatially, spectrally, directionally and temporally consistent data set – a prerequisite for subsequent quantitative and qualitative retrieval of biochemical and –physical vegetation parameters. In this study we propose and validate such a comprehensive pre-processing on a data set over rugged, mountainous terrain in the Swiss Alps.

The proposed geometric correction relies on a parametric approach taking into account the viewing geometry and geometric distortion due to the sensor, platform and topography. Potentially, this method provides high accuracy, robustness and consistent results over the full image. The performance of the geometric correction is validated relative to geolocated digital map and vector data available for parts of the CHRIS scenes.

Atmospheric correction of the hyperspectral-directional data involves the physically based radiative transfer model ATCOR. The ATCOR model corrects for the effects of the atmosphere as well as for illumination effects caused by rugged terrain influencing the satellite image. Parallel to the spaceborne data also spectro-directional ground data have been acquired with the FIGOS Goniometer over an alpine meadow. Spectral measurements of various field targets complement the data set. The field data allow for a validation of the obtained top-of-canopy Hemispherical-Directional-Reflectance-Factor (HDRF) in its full directional resolution.

1. TEST SITE AND FIELD DATA

The test site for this study is located in the Eastern Ofenpass valley, which is part of the Swiss National Park (SNP). The Ofenpass represents an inner-alpine valley on an average altitude of about 1900 m a.s.l with annual precipitation of 900-1100 mm. The south-facing Ofenpass forests, the location of the field measurements, are largely dominated by mountain pine (*Pinus montana ssp. arborea*) and some stone pine *(Pinus cembra* L.) [4][10]. These forest stands can be classified as woodland associations of *Erico-Pinetum mugo* [10]. Unique ground based characterization of the canopy structure, biochemistry and optical properties of the canopy elements were conducted in summer 2002 using various instruments, ranging from non-destructive spectroradiometric measurements to dry biomass estimation of needles [2].

Parallel to the CHRIS/PROBA acquisition of June 26, 2004, spectro-directional ground data have been acquired with the FIGOS Goniometer over an alpine meadow (Figure 1). The canopy development of meadow was still in an early phenological stage with sparse vegetation cover due to the alpine altitude of the site. Also field spectra of several land surface types were collected with the ASD FieldSpectrometer in nadir measurement configuration, 1.5 m above the ground and within 2 hours of solar noon under clear sky conditions. All spectra were converted to absolute reflectance by reference measurements over a Spectralon panel with known spectral properties.

Proc. of the 3rd ESA CHRIS/Proba Workshop, 21–23 March, ESRIN, Frascati, Italy, (ESA SP-593, June 2005)

Figure 1: Acquisition of HDRF data on an alpine meadow in the Swiss National Park using RSL's Field Goniometer System (FIGOS).

2. CHRIS DATA ACQUISITION

CHRIS/PROBA acquisitions over the SNP site amounted in the time between December 2003 and February 2005 to seven scenes. The CHRIS acquisitions have been ordered to be taken in the Land Mode 3, but several of the early scenes were acquired in the Chlorophyll Mode 4. The scene considered in this study has been recorded on June 27, 2004 under partly cloudy conditions (1/8th cloud cover).

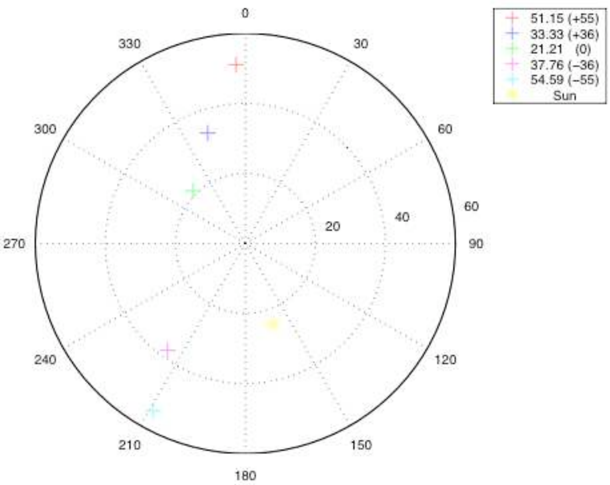

Figure 2: Polar plot of CHRIS image acquisition and illumination geometry as of June 27, 2004.

Spatial Sampling	Image area	View angles	Spectral bands	Spectral range
17m @ 556 km altitude	13 x 13 km (744x748 pixels)	5 nominal angles @ +55°, +36°, 0°, -36°, -55°	18 bands with 6-33 nm width	447-1035 nm

Table 1: CHRIS specifications for Land Mode 3.

3. GEOMETRIC PROCESSING

Given the fact that the Swiss National Park (SNP) test site is situated in high mountainous, rugged terrain, a parametric approach for geometric correction of each of the five data sets of a full CHRIS acquisition scenario (five different viewing angles) is applied. The approach is based on a 3D physical model developed by Toutin [7][8], which is implemented in the commercially available image processing software PCI/Geomatica [5]. A physical model can mathematically describe all distortions of the platform (position, velocity, orientation), the sensor (view angles, IFOV, panoramic effects), the Earth (ellipsoid, relief) and the cartographic projection. Such a model needs both orbit and sensor information, as well as a small number of ground control points (GPC's) to compute and refine the parameters of the mathematical model [9]. Typical orbit and sensor information required comprises sensor altitude, orbital period, eccentricity, actual inclination [1], sensor across- and along track angle and IFOV. Required image scene information are pixel spacing at nadir, the approximate scene center, as well as the underlying ellipsoid and a digital elevation or surface model.
Information concerning the individual viewing geometries of the five processed CHRIS data sets (view angles) are given in Tab. 2:

CHRIS file name	Chrono-logical image order	FZA" [°]	Obs. zenith angle [°]*	Obs. azimuth angle [°]*	Across track angle [°]+	Along track angle [°]+
42AC	1	+55	+51.15	177.01	3.70E	51.11S
42AA	2	+36	+33.33	161.17	11.98E	31.90S
42A9	3	0	+21.21	135.20	15.34E	15.34S
42AB	4	-36	-37.76	36.20	24.49E	32.07N
42AD	5	-55	-54.59	28.88	34.10E	50.93N

Table 2: CHRIS image acquisition geometry as of June 27, 2004.

The number of GCP's required is a function of e.g., available orbit and sensor information, GCP accuracy and final expected accuracy, but does normally not exceed 10 points. Generally, an iterative least-square adjustment process is applied when more GCP's than

" Fly-by zenith angle

* included in CHRIS HDF 4.1

+ Needed by PCI/Geomatica

the minimum number required by the model (as a function of unknown parameters) are used [9]. A digital surface model derived from ERS1/2 tandem data is used for the part of the CHRIS scene that lies within Switzerland (spatial resolution 25m), whereas SRTM-3 data (3 arc-seconds, spatial resolution 90m, interpolated to 25m) is used for the neighbouring areas in Northern Italy. Given the coarser resolution of the elevation data in the southern part of the CHRIS scene and the absence of almost any potential GCP's in this region due to its remote location, an attempt was made to select GCP's both within the whole CHRIS image, but also within the specific region of interest (the Ofenpass valley) in order to increase the locational accuracy within this specific area. High locational accuracy of the five CHRIS scenes after geometric correction is a prerequisite for reliable retrieval of HDRF information from the data set. The root mean square errors (RMSE) of the respective scenes (identified by their FZA angles) are given in Tab. 3 for GCP's selected within the whole CHRIS scenes, and in Tab. 4 for GCP's located only within the actual test site where various ground measurement data were collected (see Chapter 1).

RMSE [pixels]	+55°	+36°	0°	-36	-55°
Total	1.12	2.91	0.76	2.85	1.58
X	0.91	2.15	0.42	2.37	1.13
Y	0.65	1.96	0.64	1.59	1.11
# of GCP's	8	11	7	10	9

Table 3. RMSE for GCP's selected within the whole CHRIS scenes for a parametric geocoding approach.

RMSE [pixels]	+55°	+36°	0°	-36	-55°
Total	0.88	0.58	0.76	0.90	0.36
X	0.56	0.18	0.42	0.51	0.22
Y	0.64	0.55	0.64	0.74	0.28
# of GCP's	5	7	7	8	5

Table 4. RMSE for GCP's selected within a subpart (actual SNP test site) of the CHRIS scenes for a parametric geocoding approach.

A qualitative example of the accuracy that could be achieved by applying a parametric geocoding approach to the CHRIS data set of the SNP test site is given in Fig. 3 for FZA=0° (the actual observation angle is +21.21°). It is obvious from Fig. 3 that the overlaid vector data fits well to the CHRIS image data after geometric correction.

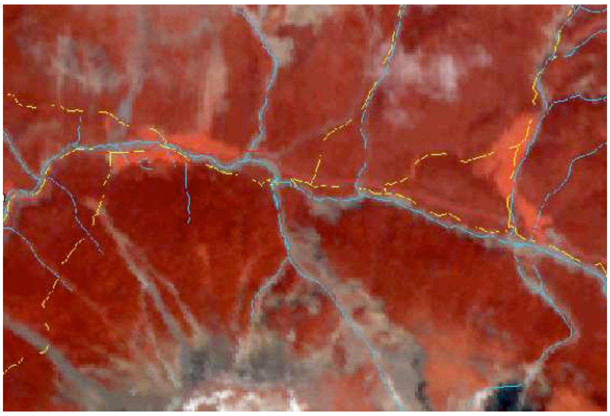

Figure 3. Geometrically corrected CHRIS image (FZA=0°) of the SNP test site with overlaid vector data (CHRIS bands 1,5 and 16).

4. ATMOSPHERIC PROCESSING

Atmospheric correction of the CHRIS radiance data is performed using ATCOR-2/3 [6], which is based on MODTRAN-4. While ATCOR-2 is generally used to atmospherically correct data from optical spaceborne sensors assuming flat terrain conditions, ATCOR-3 accounts for terrain effects by incorporating DEM data and their derivatives such as slope and aspect, sky view factor and cast shadow. ATCOR-3 is therefore suitable for atmospheric correction of sensor data acquired over rugged terrain. ATCOR-3 has recently been adapted to include the option to process tilted sensors by accounting for varying path lengths through the atmosphere and varying transmittance. CHRIS Land Mode 3 has newly been implemented in ATCOR-2/3. Given the high altitude of the SNP test site (1900 msl), a horizontal visibility of 50km and a rural aerosol model are assumed for atmospheric correction. The results of geometric and atmospheric processing of the June 27, 2004 CHRIS scene over the SNP test site can be seen in Fig. 4 for the FZA = +55° data set, in Fig. 5 for FZA = +36° and in Fig. 6 for FZA = 0°, respectively. The effects of digital elevation data used in geometric processing, being of great importance in rugged terrain, is clearly visible at the scene edges. The FZA = +36° scene was acquired exactly in the solar principle plane, resulting in strong sun glint effects present on Lake Livigno (see Fig. 2 and Fig. 5).

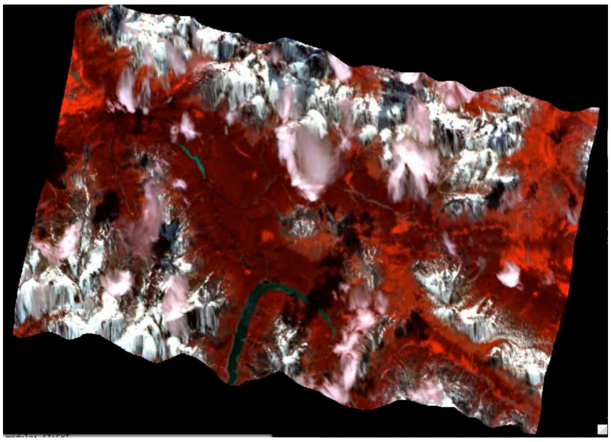

Figure 4: Geometrically and atmospherically corrected CHRIS scene (FZA = +55°) over SNP test site.

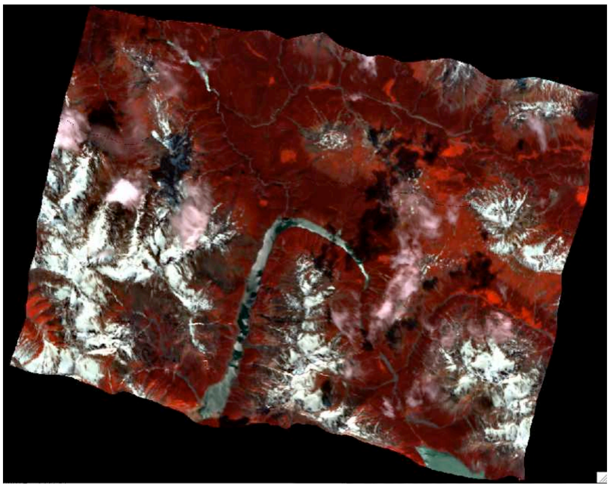

Figure 5: Geometrically and atmospherically corrected CHRIS scene (FZA = +36°) over SNP test site.

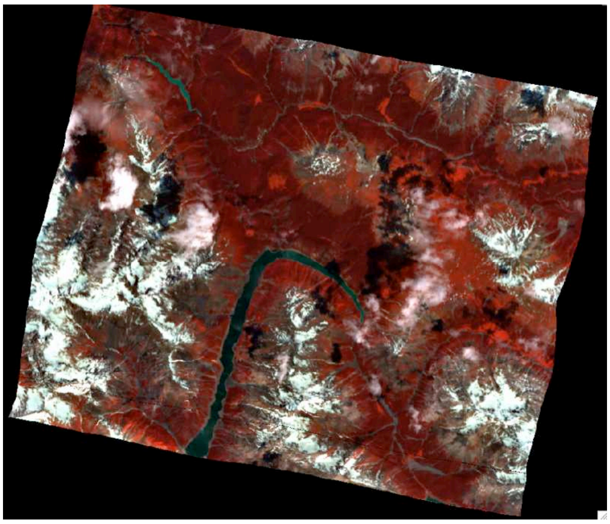

Figure 6: Geometrically and atmospherically corrected CHRIS scene (FZA = 0°) over SNP test site.

Validation of atmospheric processing

Validation of the atmospheric processing is performed through comparison of corrected CHRIS spectra versus dedicated spectral ground measurements of a meadow, performed with an ASD spectroradiometer during CHRIS data take, as well as a ROSIS data set that was acquired in summer 2002 (mountain pine trees). Fig. 7 and Fig. 8 show a comparison of atmospherically corrected CHRIS data (FZA=0° data set) and spectral ground measurements for an alpine meadow and mountain pine trees. It can be concluded from the validation that the atmospherically corrected CHRIS data fit the ground measurement data well, except for the Land Mode 3 channels 1 (442 nm), 17 (905 nm) and 18 (1019 nm). All other channels lie within the ±1 stdev margins of the ground measurements. Based on these findings, recalibration coefficients, as shown in Fig. 9, are proposed for the CHRIS data sets, based on inflight vicarious calibration data from an alpine meadow in the test site.

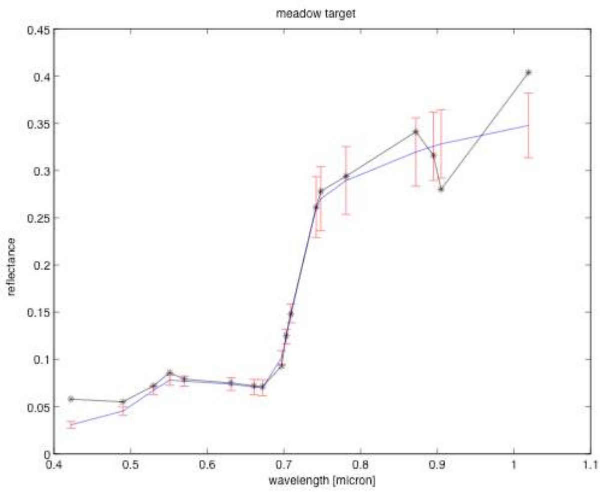

Figure 7: Comparison of atmospherically corrected CHRIS data (Land Mode 3, black line) and ground measured spectral data for an alpine meadow (blue line). The variation of ±1 stdev of the ground measurements from the mean is indicated by red bars.

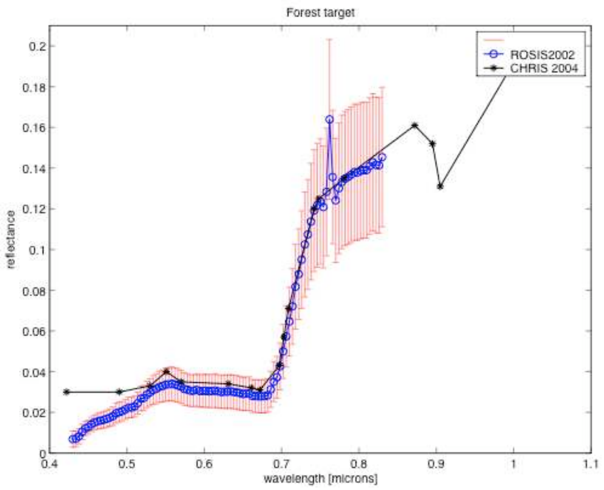

Figure 8: Comparison of atmospherically corrected CHRIS data (Land Mode 3, black line) and spectral data for mountain pine trees acquired by the airborne imaging spectrometer ROSIS (blue line). The variation of ±1 stdev of the ground measurements from the mean is indicated by red bars.

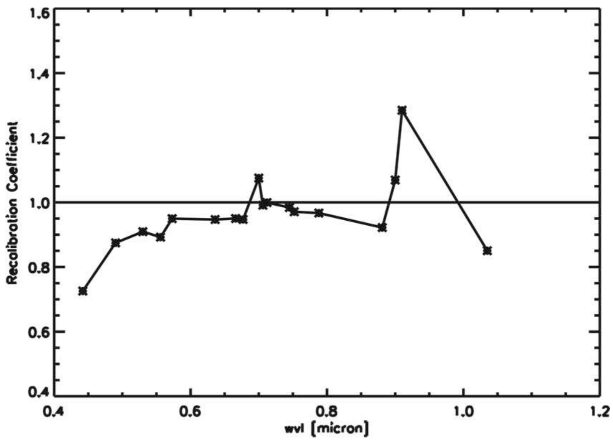

Figure 9: CHRIS recalibration coefficients derived from an inflight vicarious calibration experiment on an alpine meadow.

5. CONCLUSIONS AND OUTLOOK

HDRF measurements performed on an alpine meadow with FIGOS one day prior to the CHRIS data take have been compared to actual directional data acquired by CHRIS. HDRF data from FIGOS (see Fig. 10) that correspond to the CHRIS viewing geometries (see Fig. 11) show same trends for forward and backward scattering angles in the VIS wavelength range. However, forward scatter effects, which are untypical for vegetation cover, are more pronounced in the FIGOS measurements (see green line in Fig. 10). They may result from the very sparse vegetation cover of the alpine meadow, allowing for considerable influence of the soil background that results in forward scatter effects. These effects may be less pronounced in the CHRIS data as a result of upscaling.

The pre-processed CHRIS data also exhibit distinct HRDF signatures for a number of different land surface types presented in Figure 12.

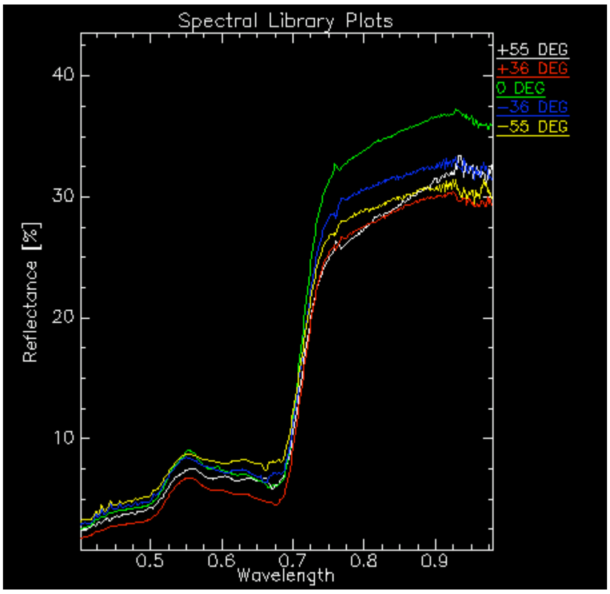

Figure 10: Reflectance data of an alpine meadow as measured in the field with FIGOS.

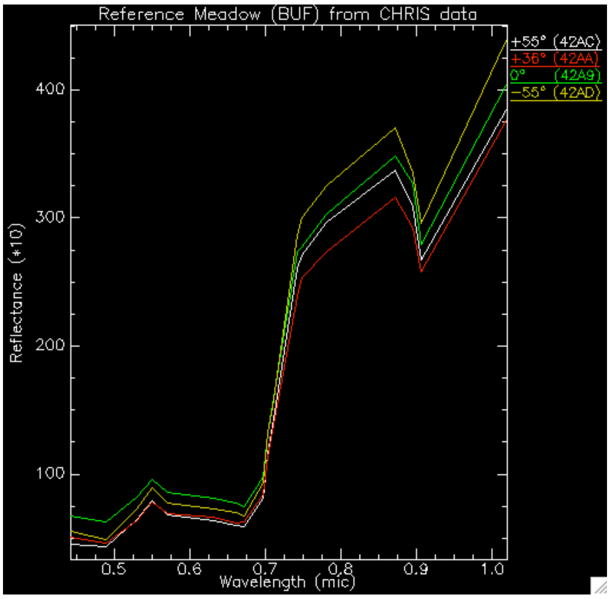

Figure 11: Reflectance data of an alpine meadow derived from CHRIS data of the varying viewing angles. (Data is missing for the FZA = -36° scene due to clouds).

It can be concluded from this study that a 3D physical model for geometric processing (parametric geocoding approach) has been successfully applied to a full CHRIS acquisition data set (five different viewing angles) over rugged terrain. Atmospheric processing of a CHRIS data set has been performed using ATCOR-3. ATCOR-3 uses digital elevation data and it is adapted to account for tilted angle sensors (varying path length and transmittance).

The demonstrated comprehensive pre-processing provides the means for a geometrically, radiometrically and directionally consistent multi-temporal CHRIS data set. Such a data set allows for the application of a physically based estimation of biochemical and –physical vegetation parameters exploiting the spectral and directional information dimension. The temporal dimension of the CHRIS data provides changing canopy background, e.g., snow surface of a winter scene relative to understory in summer, which enhances significantly the directional signature of a forest canopy [3]. The HDRF of different land surface types in the SNP test site, as retrieved from CHRIS data, is given for two wavelengths in Figure 12.

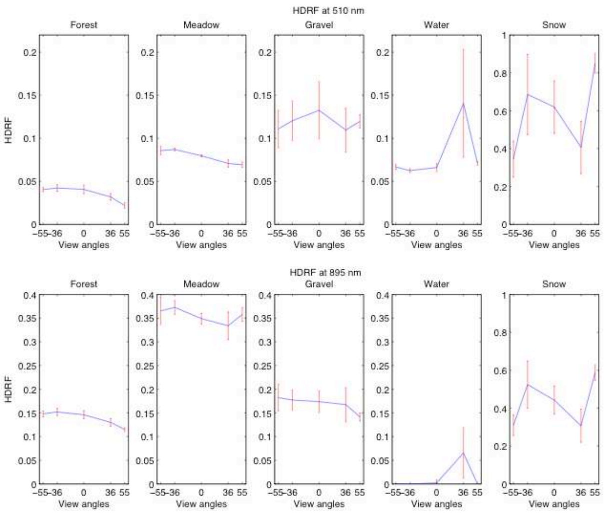

Figure 12: CHRIS HDRF of different land surface types at two wavelengths (551 nm and 895 nm).

6. REFERENCES

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